Interim Progress Report submitted to NOAA's Human Dimensions of Global Change Research (HDGCR) Program

Project Title
Sensitivity of Boulder Colorado's Water Supply to Climate Change

Investigators, including Full Contact Information

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I. Preliminary Materials

A. Project abstract

Few local governments in areas that are vulnerable to climate change have conducted an in-depth analysis of how they could be affected and how they might have to change their operations or infrastructure.

The City of Boulder, Colorado, recently analyzed how its water supply system could be affected by a repeat of drought events from the last 300 years of climate, as reconstructed through tree ring analysis. That study included some sensitivity analyses on climate change.

This project will study the potential effects of climate change in combination with a repeat of long-term climate variability. It will analyze how snowpack accumulation and runoff patterns could be affected by changes in climate that could occur by 2030. It will then analyze how much of a reduction in runoff would result in missing water supply reliability targets and, based on the analysis of output from many climate change models, the rough likelihood of such an event. Finally, it will analyze two relatively extreme wet and dry climate change scenarios to see how the water supply system could be affected.

B. Objective of research project

The project addresses how water supply planners can account for changes in variability and mean climate in their long-term planning. Typically, water planning is done by examining observed climate, and using it to estimate intensity and frequency of extreme events and to plan for the most events on record. However, analysis of climate preceding the observed record, reconstructed from tree rings and other sources, often shows that extreme events in the past were more severe than what is in the much shorter record of observations. In addition, climate change resulting from increased greenhouse gas concentrations will raise average temperatures and increase the intensity of the hydrologic cycle. This means that extreme events in the future could be more severe.

C. Approach

In this study we will attempt to integrate the analysis of climate variability and climate change with an analysis of Boulder's coping capacity. The work will be carried out in four tasks:

1. *Analyze effects of temperature on snowpack and demand.* Stratus Consulting will estimate changes in snowpack and seasonality of runoff from

incremental increases in temperature (e.g., +1°C, +2°C, +3°C). Based on the analysis of the MAGICC/SCENGEN model developed by Dr. Tom Wigley of the National Center for Atmospheric Research, a 1.5°C warming has the highest probability for Colorado by 2030. Hydrosphere Inc. will use the snowpack and runoff results from Stratus Consulting as inputs to the City of Boulder's Boulder Creek Watershed Model to examine the effects of a 1.5°C warming on supply, demand, and reliability. The analysis will be done by combining changes in runoff with a reconstruction of the 1566-2002 streamflow in middle Boulder Creek. We have applied a bootstrapping approach to match reconstructed streamflow in years prior to climate observations with years during the period of climate observation. This yields a temperature and precipitation data set consistent with the reconstructed streamflow data set. This approach effectively includes long-term variability and combines it with climate change.

Stratus Consulting will use the Snowmelt Runoff Model (SRM), which estimates the size of snowpack and timing of snowmelt, and WATBAL, a water balance model, to estimate runoff into the creeks feeding Boulder's water supply. The analysis will be conducted for the Front Range. Since there is a high correlation between runoff in the Front Range and runoff in the Upper Colorado River, we will use the changes in runoff in the Front Range to represent changes in the Upper Colorado River runoff. This is important because Boulder draws some of its supplies from the Colorado River.

2. *Determine coping thresholds*. Hydrosphere will use the Boulder Watershed Model, which simulates all significant aspects of hydrology, water rights, water storage, and diversion facilities, as well as water uses and return flows in the Boulder Creek basin, to examine the ability of the city to meet water demands under climate change. To determine what the threshold for acceptable reductions is, Hydrosphere will examine 5%, 10%, and 15% reductions in runoff imposed on the 1566-2002 record. City of Boulder staff will analyze the results to determine what level of long-term reduction in supply would exceed the city's coping capacity. That level will be considered the threshold coping capacity for the City of Boulder.

3. *Examine the likelihood of exceeding the coping capacity*. Stratus Consulting will work with Dr. Wigley to use the results of MAGICC/SCENGEN to examine the likelihood of exceeding the coping capacity by 2030 and 2070. MAGICC results will be used to develop a probability density function of changes in global mean temperature at 2030 and 2070 (the years are approximations and indicative of decadal climate changes). SCENGEN allows for comparison of regional patterns of temperature and

precipitation changes across 17 general circulation models (GCMs). The output gives an indication of what magnitudes and ranges of regional change in temperature and precipitation are possible. Using the runoff tables developed in Task 1, we will determine what increases in temperature and changes in precipitation could result in runoff reductions that would exceed the coping capacity for Boulder. We will then look at the distribution of GCM output and determine the proportion of GCMs that would result in exceedence. This is not a probability analysis (for one reason, GCM output cannot be interpreted as random independent outcomes), but gives some insight into rough likelihoods of reductions in supply severe enough to exceed Boulder's coping capacity. We will also use the results of the Statistical Downscaling Model applied to the United Kingdom Hadley general circulation model (HadCM3).

4. *Examine driest and wettest GCMs*. We will use the output of the driest and wettest GCMs (i.e., the combination of temperature increase and precipitation decrease from individual GCMs that result in the greatest increase or decrease in runoff) to estimate changes in supply and demand. Stratus Consulting will estimate changes in runoff and demand, and Hydrosphere will use the results to examine implications for Boulder's water management. The results will interpreted by city staff.

D. Description of any matching funds used for this project

The City of Boulder is providing staff time to participate in meetings and analyze results.

II. Interactions

A. Description of interactions with decision-makers who were either impacted or consulted as part of the study; include a list of the decision makers and the nature of the interaction; be explicit about collaborating local institutions

Carol Ellinghouse is the Coordinator of Water Resources in the City of Boulder's Utility Division. She is representing the City on the project. Lee Rozaklis, who will be a subcontractor, runs Boulder's water management model. Both are participating in the project and are being consulted about all major decisions.

B. Description of interactions with climate forecasting community (i.e., coordination with NOAA climate forecasting divisions, the International Research Institute for climate prediction (IRI), regional or local climate forecasting entities, etc.)

We are coordinating closely with Dr. Connie Woodhouse of NOAA. Dr. Woodhouse provided a 400-year reconstruction of streamflow on Middle Boulder Creek. We are consulting with her on how to use that record and combine it with climate change scenarios. Dr. Tom Wigley is a consultant to the project on the application of climate change models. We are also consulting with Dr. Klaus Wolter of NOAA on the use of observed climate data. We have also consulted with Dr. Rajagopalan Balaji of the University of Colorado on techniques for selecting analog years in the observed climate record to represent the period of paleoclimatic reconstruction.

C. Coordination with other projects of the NOAA Climate and Societal Interactions Division (i.e., other HDGCR, Research Applications, or Regional Integrated Sciences and Assessments projects)

We are coordinating with Brad Udall, who coordinates the Western Water Assessment at the University of Colorado.

III. Accomplishments

A. Brief discussion of research tasks accomplished. Include a discussion of data collected, models developed or augmented, fieldwork undertaken

We have collected observed climate data for weather observation sites in catchment for Boulder's water supply. We have also obtained the reconstructed streamflow data from Dr. Woodhouse.

Dr. Kenneth Strzepek of the University of Colorado and K. C. Hallet, a graduate student at CU and intern at Stratus Consulting, have developed, in consultation with Dr. Balaji, a technique for selecting analog years to represent the years in the paleoclimate reconstruction. Temperature and precipitation data are needed for the paleoclimate years in order to apply climate change scenarios. We select the runoff in the years in the observed climate record that have the closest runoff to the reconstructed streamflow years (using the reconstruction for recent years as well as prehistoric years). This uses a random selection function, which gives the most weight to the years with observed climate record with the closest streamflow to the years in the paleoclimate data. The 400-year record is represented by a series of years in the observed climate record (e.g., 1952 to the present). We can then take the temperatures and precipitation from the observed record as an analog of the 350 years preceding the observed climate data.

We are in the process of calibrating the Snowpack Runoff Model (SRM), which will be used to estimate change in snowpack and discharge of meltwater. We are also calibrating WATBAL, which will model runoff from the snowpack and below where snow accumulates into the rivers and streams that feed Boulder's water supply. Output from SRM and WATBAL will be fed into Hydrosphere's Boulder Creek Watershed Model, which assesses supply and demand of water for Boulder.

B. Summary of any preliminary findings (i.e., how this research advances our scientific understanding)

Preliminary analysis of the climate change scenarios show that all scenarios project higher temperatures for the region. The models differ on precipitation; some project increased precipitation, while others project reduced precipitation. The models tend to project increased precipitation in the winter and decreased precipitation in the summer.

C. List of any papers and presentations arising from this project thus far; please send reprints of journal articles as they appear in the literature

N/A

D. Discussion of any significant deviations from proposed work plan (e.g., delayed fieldwork due to late arrival of funds).

We have decided to use the model WATBAL to estimate runoff. It is simpler and easier to apply than the model we originally planned to use – the PRSM.

IV. Relevance to the Field of Human-Environment Interactions

A. Describe how the results of your project are furthering the field of understanding and analyzing the use of climate information in decision making

We are developing a technique that can combine historic climate variability and change to help decision makers in adapting to both kinds of outcomes, i.e., climate change imposed on top of increased variability.

B. Where appropriate, describe how this research builds on any previously funded HDGEC research (i.e., through NSF, EPA, NASA, DOE, NGOs, etc.)

N/A

C. How is your project explicitly contributing to the following areas of study?

1. **Adaptation to long-term climate change**
   Project is addressing long-term adaptation to climate change by examining scenarios of increases in temperature and change in

precipitation. It is intended to inform stakeholders about the potential need for adaptation.

2. **Natural hazards mitigation**
   We will examine potential vulnerability to sustained drought by incorporating the paleoclimate record on drought and adding climate change on top of natural variability.

3. **Institutional dimensions of global change**
   We are working with the City of Boulder on incorporating consideration of climate change in its long-term planning.

4. **Economic value of climate forecasts**
   We will not be explicitly addressing economic value of climate change forecasts.

5. **Developing tools for decision makers and end-users**
   We are applying MAGICC/SCENGEN in developing climate change scenarios. We are also developing a technique to convert streamflow reconstructions into analog temperature and precipitation records.

6. **Sustainability of vulnerable areas and/or people**
   We are examining the long-term sustainability of Boulder's water supply.

7. **Matching new scientific information with local/indigenous knowledge**
   We are working closely with decision makers on making climate change and variability information relevant to their needs.

8. **The role of public policy in the use of climate information**
   We are working through the City of Boulder's planning process to incorporate information on climate variability and change.

9. **Socioeconomic impacts of decadal climate variability**
   The analysis is using the paleoclimate record to incorporate climate variability in planning, and we are imposing a long-term change in climate on top of that record. The City of Boulder will consider the impacts of changes in climate variability as expressed in the paleoclimate reconstruction.

10. **Other (e.g., gender issues, ways of communicating uncertain information)**
    N/A

V. Graphics

N/A